

## Equipment Reliability Process in Krško NPP

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### ABSTRACT

To ensure long-term safe and reliable plant operation, equipment operability and availability must also be ensured by setting a group of processes to be established within the nuclear power plant. Equipment reliability process represents the integration and coordination of important equipment reliability activities into one process, which enables equipment performance and condition monitoring, preventive maintenance activities development, implementation and optimization, continuous improvement of the processes and long term planning.

The initiative for introducing systematic approach for equipment reliability assuring came from US nuclear industry guided by INPO (Institute of Nuclear Power Operations) and by participation of several US nuclear utilities. As a result of the initiative, first edition of INPO document AP-913, 'Equipment Reliability Process Description' was issued and it became a basic document for implementation of equipment reliability process for the whole nuclear industry.

The scope of equipment reliability process in Krško NPP consists of following programs: equipment criticality classification, preventive maintenance program, corrective action program, system health reports and long-term investment plan. By implementation, supervision and continuous improvement of those programs, guided by more than thirty years of operating experience, Krško NPP will continue to be on a track of safe and reliable operation until the end of prolonged life time.

**Keywords:** *reliability, safety, criticality, optimization, improvement*

### 1 INTRODUCTION

Most events on Nuclear Power Plants are caused by errors on plant equipment. Errors can be mechanical, electrical or instrumentation/control caused and they often cause failure of equipment. Dependent on equipment importance or criticality for plant operation and safety, failure of certain equipment may have different consequences for the plant. For example, it can bring to plant shutdown, reduction of power, unplanned entrance into Technical Specification Limiting Condition of Operation (TS LCO), loss of safety functions, etc.

Preventive maintenance program (PM) has important role in ensuring good condition of plant equipment. It is important to perform proper preventive activities within proper time intervals, especially on the most significant plant equipment. Due to the equipment criticality classification and other available criteria, PM Programs are continuously optimized to assure that human and financial recourses for preventive maintenance are properly used to have maximum equipment availability and minimum equipment failures.

Performance monitoring of systems, structures and components (SSC) condition is essential to detect early indicators of SSC degradation and to act in a timely manner to prevent failures. System Health Reports reflect SSC condition by grading the systems due to their performance,

recognise insufficiencies and propose measures for improvement (maintenance activities, equipment replacement, design modifications, etc.).

Long term planning of investments on the plant is needed to address all necessary equipment replacements or design modifications and to ensure necessary funds for the investments. Proper prioritization of investments gives the proposed time intervals in which the investments are going to be implemented. Prioritization is made considering various different factors, like current condition of the SSC, unavailability of spare parts, regulatory requirements, radiation dose reduction, influence on plant operation or maintenance, industrial safety, etc. Proper planning and prioritization assures that all plant equipment will be operable/available and will positively affect long term safe and reliable plant operation.

By integration of all important activities/processes which contribute to reliable SSC operation into one process, we have the ability to systematically carry out, control and continuously improve the Equipment Reliability Process.

## 2 EQUIPMENT RELIABILITY PROCESS SCOPE

Equipment Reliability Process, due to INPO AP-913 [1] consists of five basic elements:

- Scoping and Identification of Critical Components
- Performance Monitoring
- PM Implementation
- Corrective Action
- Continuing Equipment Reliability Improvement
- Life Cycle Management

Graphical illustration of the process scope is shown in Figure 1.

### Equipment Reliability Process Top Level Diagram

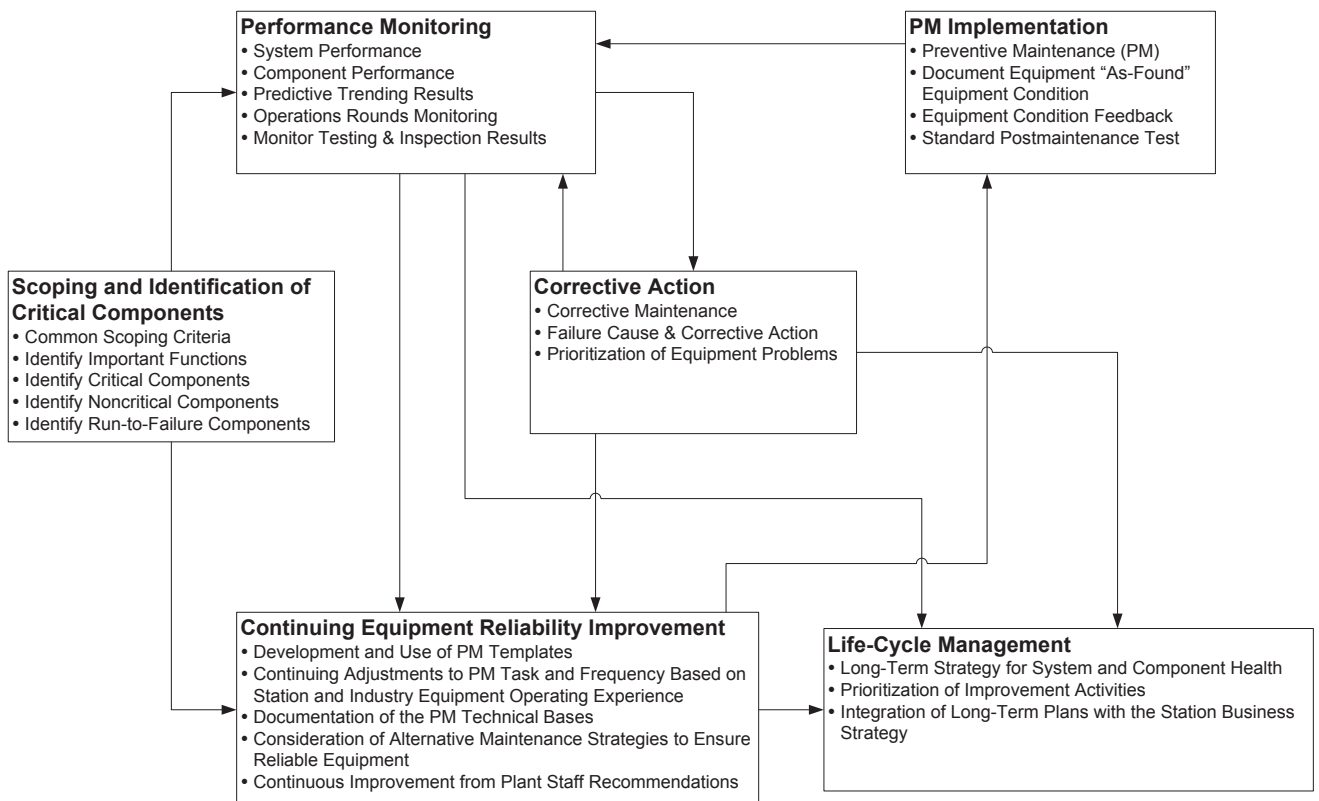


Figure 1: Equipment Reliability Process Top Level Diagram [1]

In Krško NPP we follow the recommendations from the INPO AP-913. Equipment Reliability Process that we implement consists of following elements:

- Equipment Criticality (ECR)
- Preventive Maintenance Program (PM)
- Corrective Action Program (CAP)
- System Health Report (SHR)
- Long-Term Investment Plan

## 2.1 Equipment Criticality (ECR)

Equipment Criticality is classification of plant equipment into categories based on equipment significance for plant reliable operation and consequences that the failure of equipment is going to have on plant operation. The goal of equipment criticality classification process is to put equipment into different criticality categories and to enable optimization of PM activities performed on equipment based on their criticality. That means, if failure of certain equipment has no major direct influence on plant operation, resources for PM activities on that equipment should be reduced or even abolished. On the other hand, if failure of certain equipment has major direct influence on plant operation, there should be more PM activities on that equipment, they should be executed in shorter time intervals, therefore more resources should be used to maintain that kind of plant equipment. To conclude, equipment criticality enables the plant to optimize the resources for PM on equipment in order to assure reliable plant operation.

There are different methodologies and approaches for criticality classification. The methodology that we use in Krško NPP is to answer the questions considering consequences of equipment failure to plant operation and dependent on the first question answered YES, criticality is determined. We divided equipment into for criticality categories:

1. CC1 – Critical equipment category 1
2. CC2 – Critical equipment category 2
3. NC – Non - Critical equipment
4. RTF – Run to fail

Besides the equipment category, we also mark subcategory that in fact is indicating question that is answered YES. For example, if criticality is CC1-4, it means that equipment is critical category 1 and 4<sup>th</sup> question that defines this category is answered YES.

Single point vulnerability (SPV) equipment is subcategory of Critical equipment category 1 and consists of CC1-1, CC1-2 and CC1-3 subcategories, which means that one of the three first questions is answered YES. Definition of SPV that we have in Krško NPP is that the failure of equipment that is classified as SPV will cause one of the three consequences:

1. Automatic reactor or turbine trip (shutdown)
2. Power reduction for more than 5%
3. Demand for manual reactor or turbine trip (shutdown)

There are total of 18 questions that define equipment criticality. First five questions define Critical equipment category 1, next five questions define Critical equipment category 2 and the last eight questions define Non - Critical equipment. If all questions are answered NO, equipment is classified as run-to-fail (RTF). RTF means that failure of equipment will not have consequences on plant operation and it is more economical to replace or repair equipment when it fails then to carry out PM activities on equipment. In Krško NPP we are careful with abandoning PM activities based on criticality classification and we also consider other factors, like our own experience on equipment (PM results, test results, equipment history back log), industry experience and other factors available.

Methodology for criticality classification determination is shown in table 1.

<u>CC1 – Critical equipment category 1</u>	
<ol style="list-style-type: none"> <li>1. Is failure of the component going to cause automatic reactor/turbine trip?</li> <li>2. Is failure of the component going to cause power reduction more than 5%?</li> <li>3. Is failure of the component going to cause demand for manual reactor trip?</li> <li>4. Is failure of the component going to cause an entry into Technical Specification Limiting Condition of Operation (TS LCO) that demands plant shutdown within 7 days or less?</li> <li>5. Is failure of the component going to cause loss of risk significant Maintenance rule function?</li> </ol>	<p>} SPV</p>
<u>CC2 – Critical equipment category 2</u>	
<ol style="list-style-type: none"> <li>1. Is failure of the component going to cause loss of less significant Maintenance rule function?</li> <li>2. Is failure of the component going to cause power reduction less than 5%?</li> <li>3. Is failure of the component going to cause partial actuation of protection systems?</li> <li>4. Is failure of the component going to cause loss of function, which is 100% redundant but can cause a transient that increases risk of loss of production?</li> <li>5. Is failure of the component going to cause an entry into any Technical Specification Limiting Condition of Operation (TS LCO)?</li> </ol>	
<u>NC - Non - Critical equipment</u>	
<ol style="list-style-type: none"> <li>1. Is the component needed to for handling beyond design basis accidents?</li> <li>2. Can the failure of the component lead to outage prolongation for more than 8 hours?</li> <li>3. Is failure of the component going to cause increase of risk in the area of industrial, radiological or environmental safety?</li> <li>4. Is failure of the component going to cause violation of regulatory requests?</li> <li>5. Is failure of the component going to cause difficulties in plant supervision or maintenance or is it going to cause failure of other critical or non-critical components?</li> <li>6. Is the operability of the component needed for maintenance of other critical equipment?</li> <li>7. Are there long purchasing time intervals for spare parts that could cause difficulties in repairing the equipment in timely manner?</li> <li>8. Is it more economical to carry out PM activities on the component than to do corrective maintenance?</li> </ol>	
<u>RTF – Run to Fail</u>	
All questions above are answered NO	

Table 1: Methodology for criticality classification determination [2]

Criticality has been classified for approximately 100.000 components. The results of classification are shown in table 2.

<b>Criticality category</b>	<b>Percentage of classified components</b>
CC1 – Critical equipment category 1	<b>12%</b>
CC2 - Critical equipment category 2	<b>15%</b>
NC – Non - Critical equipment	<b>36%</b>
RTF – Run to fail	<b>35%</b>
SPV – Single Point Vulnerability	<b>2%</b>

Table 2: Results of criticality classification

Results of criticality classification can vary from plant to plant, dependent on methodology that was used and also on the level of details in equipment database.

For equipment criticality determination ECR software application was used. It is an application developed by the plant within the existing business software. The results on criticality classification are automatically transferred to other plant applications, like MECL (Master Equipment Component List), CAP (Corrective Action Program) and Work order application. That way the information about component criticality are visible to all users and can help with prioritizing work activities as well as proper preparation for them.

## 2.2 Preventive Maintenance Program (PM)

Preventive Maintenance (PM) includes predictive, periodic and planned maintenance activities in order to keep the equipment under its design basis, ensure that equipment fulfil all of its expected functions and to prolong the equipment's life time [3].

Predictive maintenance is continuous or periodic surveillance of components to predict when the component is going to fail and to be able to prevent the failure. Results of predictive maintenance activities show the current condition of equipment and the ability to perform its functions. They are also used for equipment performance monitoring and trending and to enable for needed maintenance activities to be executed before the failure of equipment actually occurs. Examples of predictive maintenance activities: vibration monitoring, infrared thermography, lubricating oil analysis, bearing temperature analysis, isolation resistance, etc.

Periodic maintenance is performed within certain time intervals or based on time the component has been in operation (work hours). Based on available factors, time intervals can be changed, if needed.

Planned maintenance is performed based on results from predictive or periodic maintenance, manufacturer's recommendations or operating experience. It is performed before the project functions of the component are jeopardized. Planned maintenance can be performed under plant shutdown or under operation, if there is a redundant or spare component that can cover the function fulfilment while the component is out of service.

PM program is continuously evaluated and optimized. One of the criteria for PM optimization is equipment criticality classification. Based on equipment criticality, some PM activities may be introduced, cancelled, scope of activity can be changed, time periods for performing PM activities can be reduced or prolonged. Criticality is not the only criteria for PM changes. Other criteria considerable are:

1. Industry experience shows there are more efficient methods and strategies for maintenance.
2. There are new, better predictive technologies available
3. Equipment degradation is occurring in a shorter or longer time intervals than it was expected

4. Equipment has been replaced with new one
5. Information from Maintenance department are indicating there is a need for change
6. Equipment failure occurs between PM time intervals

Changes within the PM program have to be made in controlled manner. That means there is a process which defines responsibilities and jurisdictions within the process. Changes are usually proposed by component engineers within the maintenance department. The approval process goes through department superintendent, system engineer and the final approval is made by maintenance manager. The graphical illustration of the PM review approval workflow is shown in figure 2.

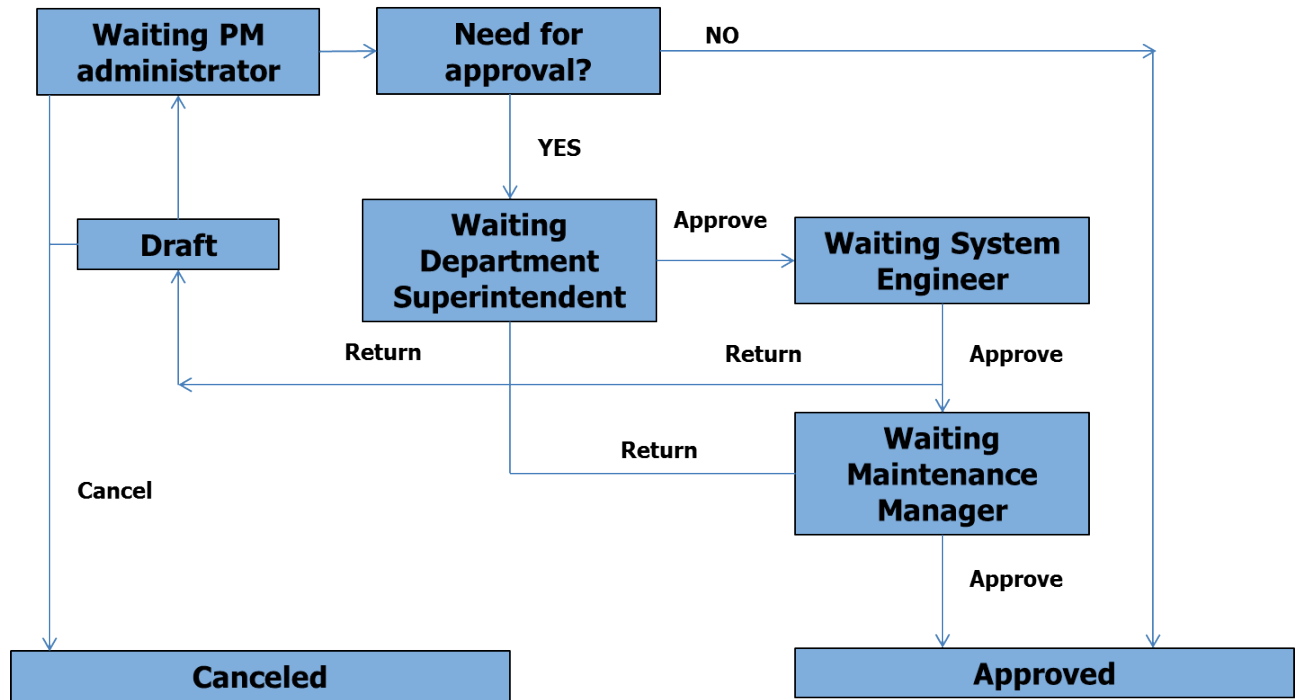


Figure 2: PM review approval workflow

The goal of the PM optimization is to perform proper PM activities on the right equipment in optimum time intervals and to allocate human and financial resources to achieve that.

### 2.3 Corrective Action Program (CAP)

The purpose of the Corrective Action Program (CAP) is to enable documenting all equipment deviations, degradations or failures, nonconformance issues or suggestions for improvement [4]. It is also used to keep track on solving equipment issues, to perform analysis for more complex issues and to give action plans for resolving them. Action plans should also prevent deviations from repeating and propose actions for improvement of equipment condition or plant processes.

The CAP process begins by issuing a Corrective Action Request (CR). Any employee on the plant can issue it. All CRs are approved by author's department supervisor or shift supervisor. CRs are processed by CAP screening team, which defines the way to solve CR, given time for solving and assign a department that is going to be responsible for solving the CR. Possible ways to solve a CR are:

1. Direct action to solve a problem - assigned when the CR can be solved directly through work order or some other direct action
2. Analyses – problem is more complex or deeper investigation is needed to propose proper actions



3. Non-conformance analyses – to prescribe actions to resolve issues when component, part or material is not meeting all original specifications (original supplier does not exist on the market any more, original part is no longer manufactured, etc.)

Process is graphically shown in figure 3.

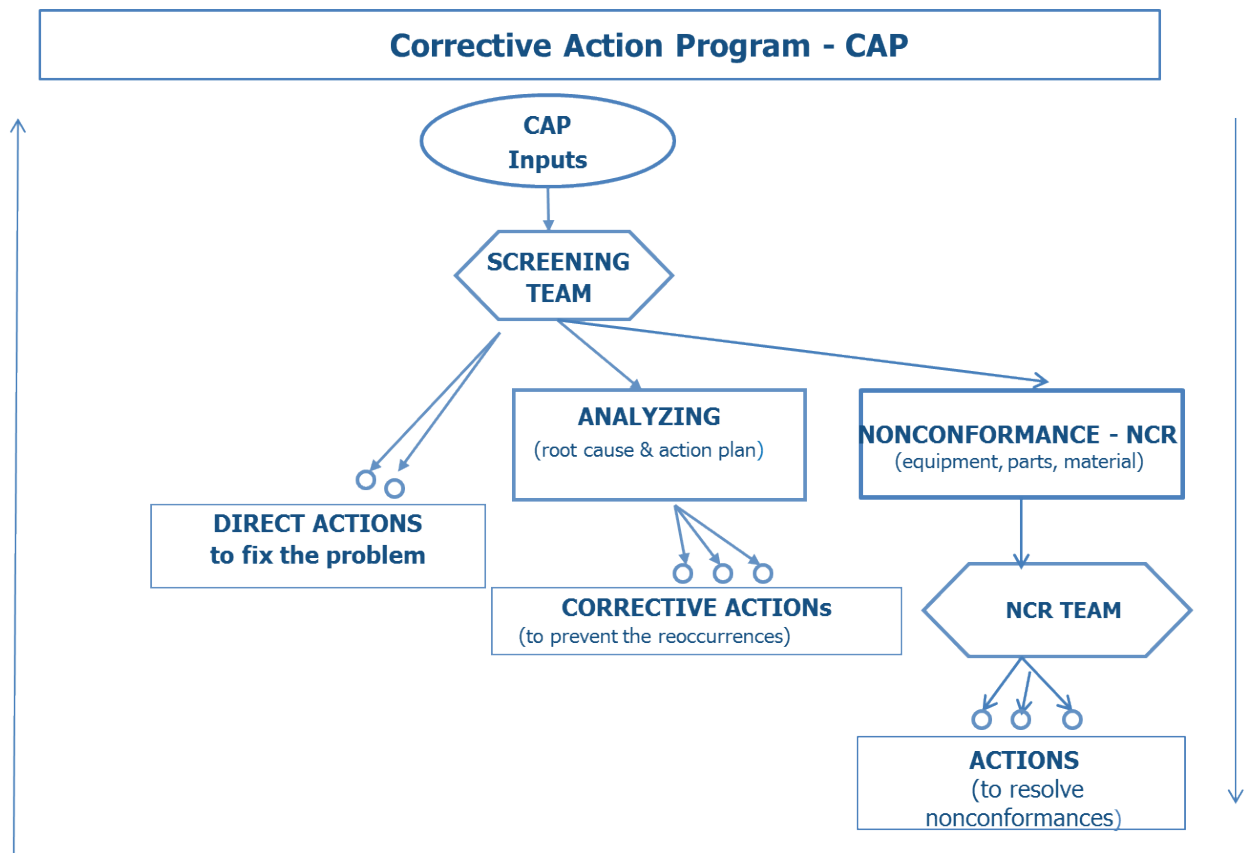


Figure 3: Corrective Action Program process

There are approximately 4000 CRs issued per year. Whole process is conducted through a software application, developed by Krško NPP. Application is connected with other major plant applications, like Equipment Database, Work Order, Equipment Criticality, Documentation Database and Maintenance Rule Application. That enables information to be shared between applications and gives a possibility to collect a lot of information considering certain equipment, its history backlog of deviations, failures, corrective work, replacements and modifications. It is a very broad and useful tool for assuring equipment reliability and collecting information to monitor the performance of equipment.

## 2.4 System Health Report (SHR)

System Health Report (SHR) is a document that describes condition (health) of the plant systems and proposes actions that has to be performed to improve the health. Intent of the SHR is to assure the information about system condition and necessary improvement activities for plant management and to be basis for composing long-term investment plan. The final goal is to ensure reliable plant operation based on frequent evaluation of plant systems condition.

SHR is written quarterly. Responsibility for writing SHR is on System Engineering department. Information for SHR is collected from available plant sources, like CAP, work order backlog, various reports, information from other departments, etc. Systems are graded based on their current condition. We use for colour grades [5]:

- Green (Satisfactory)
- Yellow (Acceptable)
- Orange (Improvement Needed)
- Red (Potential Danger)

For every grade, except Green, reasons for grade are stated as also proposed activities that have to be performed, to enable transition to higher grade. For every graded system, following aspects are evaluated [5]:

- Reasons for system grade
- Activities to be done on system to put it in a higher grade
- Function failures on the system in the last quarter
- New issues on system equipment in the last quarter
- Improvement plan for planned activities (on-line; outage)
- Prioritization recommendations for un-planned activities
- Aging and obsolescence issues on system equipment
- Major performed activities on system in the last quarter

Based on the system grade, activities are prioritized. The lower the grade is, activities will get greater importance and thus the advantage within the prioritization process. That will also effect due date in the long term investment plan.

SHRs are presented and approved on the Plant Health Committee (PHC) meetings. PHC is an expert panel comprised of representatives/managers from various plant departments: production/operations, maintenance (mechanical, electro, I&C), system engineering, licencing, independent safety evaluation group, and design modification. It's PHC responsibility to monitor and direct the Equipment Reliability Process, to recognize negative trends within the process, propose action for improvement and assure proper implementation of those actions.

## 2.5 Long-Term Investment Plan

The purpose of the Long-Term Investment Plan is to sort the equipment issues, in fact the solutions to the issues dependent on the importance or prioritization of the issue. Plan contains equipment replacements, technological upgrades and maintenance activities. It is a part of Equipment Reliability Process and it ensures long term safe and reliable plant operation. [6]

Long-Term Investment Plan has a role to establish clear view on activities, which demand larger financial or human resources, involvement of multidisciplinary teams and to assure timely preparation and implementation of those activities as well as optimum use of resources. It is a basis for preparation of other projects, like on-line or outage planning. [6]

Long-Term Investment Plan includes planning of activities for at least five years ahead. To include proposed activity in a Long-Term Investment Plan, analyses within CAP has to be performed and the result of the analyses are actions, which demand design modification process. Those kinds of actions are prioritized within the analyses due to following attributes:

- System grade in SHR
- Influence on operational effectiveness
- Influence on maintenance effectiveness
- CAP classification
- Regulatory requests
- Probabilistic Safety Analysis: influence on core damage frequency (CDF) and unwanted containment releases
- Influence on Industrial Safety
- ALARA

For every attribute certain number of points is assigned, dependent on how the proposed action affects each of the attributes. All points are then added together and the higher the overall point number is the higher priority the action will get. Off course, this prioritization process is not



the only exclusive condition for action prioritization within the Long-Term Investment Plan, but it helps in composing the plan, when it is revised. The revision of the plan is carried out at least once a year, first to keep it in a time frame of at least five years ahead and second because new issues are addressed and new prioritization of the activities within the plan can occur.

### 3 CONCLUSION

Krško NPP implements Equipment Reliability Process in accordance with industry standards. The process is comprised of several elements: Equipment Criticality (ECR), Preventive Maintenance Program (PM), Corrective Action Program (CAP), System Health Report (SHR), Long-Term Investment Plan. Every element is a process for itself and each contribute to assurance of reliable equipment operation. To be able to effectively monitor and guide the Equipment Reliability Process, coordination and integration of those individual processes is necessary.

It is important to exchange information concerning equipment reliability with other industry representatives to gather best industry practices. For this purpose, working groups for equipment reliability are established (Equipment Reliability Working Group/International Equipment Reliability Working Group). Krško NPP also participates in the activities of International Equipment Reliability Working Group.

Only with systematic approach and continuous improvements we can ensure long term safe and reliable operation of Nuclear Power Plants.

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